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FEDDE, LANDSEA & NARKINSKY

Study of Flux Distribution  
in Interpole Motors

Electrical Engineering

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**STUDY OF FLUX DISTRIBUTION IN INTERPOLE MOTORS**

**BY**

**HARRY FEDDE, ALBERT FABIAN LANDSEA  
AND  
CHARLES SOL NARKINSKY**

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**T H E S I S**

**FOR THE**

**DEGREE OF BACHELOR OF SCIENCE**

**IN**

**ELECTRICAL ENGINEERING**

-----  
**COLLEGE OF ENGINEERING**

**UNIVERSITY OF ILLINOIS**

**1912**



## UNIVERSITY OF ILLINOIS

May 28 1902

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

HARRY FEDDE, ALBERT FABIAN LANDSEA AND CHARLES MARKINSKY

ENTITLED STUDY OF FLUX DISTRIBUTION IN INTERPOLE MOTORS

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF BACHELOR OF SCIENCE IN ELECTRICAL ENGINEERING

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## STUDY OF FLUX DISTRIBUTION IN INTERPOLE MOTORS.

### I. INTRODUCTION.

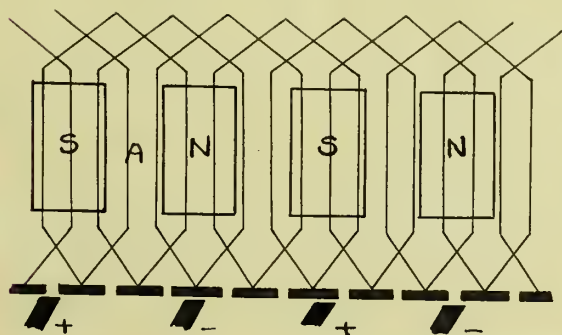
The object of this thesis is to investigate the flux distribution of a direct current motor, having commutating poles or interpoles, and to compare this with the flux distribution of the same motor having these interpoles cut out. Further investigations will be made on the motor to show the variation of the flux distribution with the speed of the motor. In order to do this work a special apparatus was designed, constructed and used in making the tests.



## II. GENERAL THEORY.

While the device of interpoles has been known for several years, it has not been put to any practical use until quite recently. To obtain sparkless commutation has been the problem of the designer for some time. The introduction of the interpole has successfully solved this problem and gives practically sparkless commutation under all conditions of load.

In the ordinary direct current motor with the brushes set on the neutral position at no load, armature reactions produce a magnetic field at this neutral, or commutating zone, when a load comes on, in the following manner. When the armature winding is carrying current its magneto-motive force tends to set up certain magnetic fields or fluxes which have a definite relation to the position of the brushes. Considered broadly, the current after entering the commutator or armature winding at any brush arm, divides into two paths of opposite direction. As the winding on each of these paths is arranged in exactly the same way, and as the currents flow in opposite directions, the armature windings in these two paths have magneto-motive forces which are in oppositedirections. The resultant armature magneto-motive force rises to a maximum at points corresponding to the brush positions as indicated at A in the Fig. Midway between these points the magneto-motive force is zero.



Magnetic fluxes are set up by these magneto-motive forces which are functions of the forces producing them, and the proportions,



dimensions and arrangement of the magnetic paths, and these magnetic fluxes will be practically fixed in position corresponding to the brush setting.

The coil undergoing commutation whose ends are connected to bars under the brush, has its sides lying in this field and in the rotation thru it an active voltage is generated between the bars.

Due to the current being reversed in the coil while the bar is passing from under the brush, the magnetic lines which exist principally around the slot in which the coil lies are also reversed and this is like the kick obtained in opening a current carrying circuit. The action induces another e.m.f. which adds to that due to armature reaction.

The total e.m.f. thus generated is practically constant for a given load and speed. It is of such a direction as to oppose the reversal of current in the coil being commutated and produces sparking.

It is ideally desirable that during the time a coil is short circuited by a brush, the coil should have generated within itself an e.m.f. opposed to the current that the particular coil carried a moment earlier. Also that the e.m.f. of the short-circuited coil should be exactly enough to stop the old current in the coil, start a new current in the opposite direction and bring the new current up to the exact number of amperes that are flowing in the coil next beyond. If all this occurs during the time that the coil is short circuited, ideal commutation will result.



The usual method employed to produce this result is to shift the brushes until the main field flux reverses the armature reaction and so generates an e.m.f. in the armature coil, which reverses the current and thus acts as commutating<sup>t</sup> flux. The magnetic flux of the field pole however, decreases with increasing load at the pole corners towards which the brushes are shifted, by the demagnetizing action of the armature reaction, and the shift of the brushes therefore has to be increased with the load. At overload the pole corners toward which the brushes are shifted may become so far weakened that even under the pole, not sufficient reversing e.m.f. is generated and satisfactory commutation ceases.

In general however, varying the brush shift with the load is not permissible and with a rapidly varying load not feasible, and therefore the brushes are set permanently at a mean shift. In this case however, instead of increasing proportionally with the load, the commutating field is maximum at no load and gradually decreases with an increase of load, and is correct for only one load. At constant shift of the brushes the commutation is best at a certain load and usually becomes poor at lighter or heavier loads, and ultimately becomes bad by inductive sparks, due to insufficient commutating flux.

This has led to the development of the commutating pole or interpole. It consists of a narrow magnetic pole located between the main poles for the purpose of setting up a local magnetic flux under which the armature coil is commutated. These poles are excited by coils in series with the armature and having a number of effective turns higher than the number of effective turns per armature pole, so that the magneto-motive force set



up opposes, overpowers and reverses the armature magneto-motive force and produces a commutating magneto-motive force equal to the product of the armature current and the difference of effective turns of pole and armature and thereby produces a commutating flux which is proportional to the load. This condition holds until the interpoles reach magnetic saturation.

Plate 1 shows the theoretical flux distribution around the armature in an interpole motor according to Steinmetz. The resultant or total flux as shown favors commutation. The c.m.f. generated under the brush is of such a direction as to reverse the current in the coil undergoing commutation.

Plate II shows the flux distribution of a non-interpolar motor. The total flux as shown is of such a value at the point of commutation as to oppose commutation. A shift of the brushes in the direction of shift of flux would produce good commutating conditions as shown on the same plate.

This question of brush setting is of great importance in relation to the interpole. The point of maximum armature magneto-motive force is definitely fixed by the brush setting. With the interpole fixed in position, any shifting of the brushes backward or forward will obviously change the shape of the resultant flux distribution under the interpole face and in consequence the flux distribution will be changed.

The advantages of the interpole over the shift of brushes thus is that the commutating flux of the former has the right intensity at all loads, while the latter is right only at one particular load, too high below that load, too low above it.



### III. METHOD.

To obtain the flux distribution, the pilot brush method was used. This consists in reading the pressure at equal angular increments along the commutator, from one commutating position or brush, to the next. To accomplish this a special pilot brush and holder were constructed. A graduated arc was fastened to the rocker arm of the machine by means of brackets as shown in Fig. 2. On this arc was fitted a slider which held the brush. This slider could be firmly fastened at any point on the arc by means of a set screw. Thus a definite angular relation between the brushes and the pilot brush always existed.

The method of procedure was as follows. One terminal of a voltmeter was connected to one of the brushes as shown in Fig. 2. The other terminal of the voltmeter was connected to the pilot brush. Now as the pilot brush is moved around the commutator it will include more and more armature coils between itself and the brush. Each coil in cutting through the field flux will at constant speed, generate an e.m.f. which is proportional to the flux cut. Readings of pressure were taken for each 10 electrical degrees between two brushes.

If the integrated pressure curves are plotted with the measured pressures as ordinates and electrical degrees as abscissae the flux wave may be derived from these curves as follows.

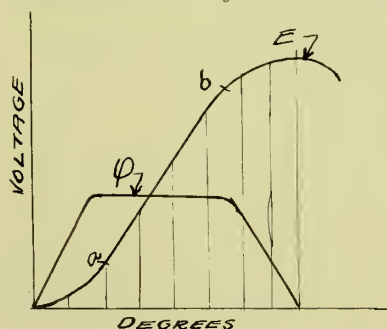


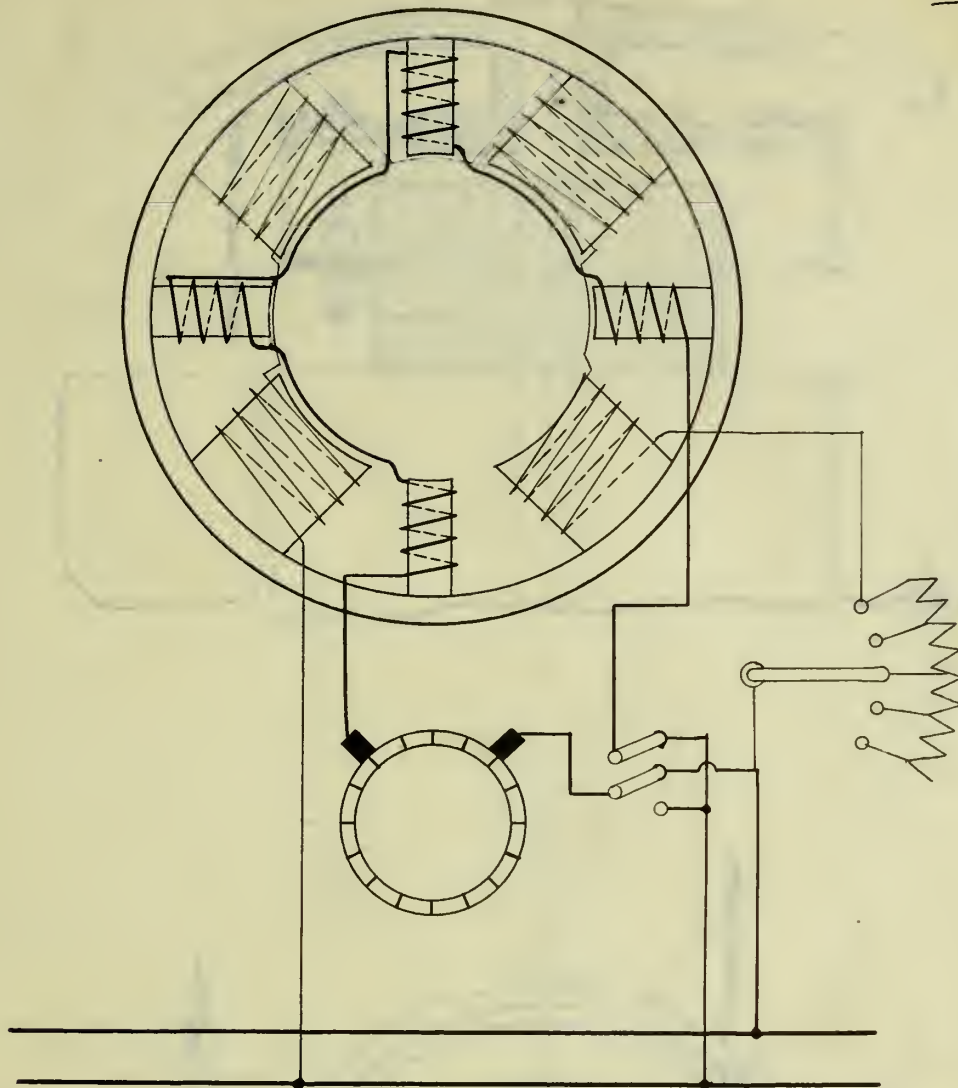
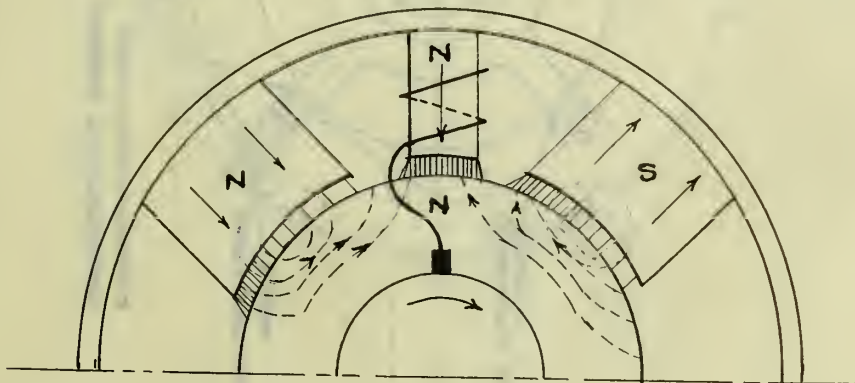
Fig. A. represents an e.m.f. wave and the derived flux wave. E is the e.m.f. wave obtained as described above. Ordinates are drawn at intervals of 10 electrical

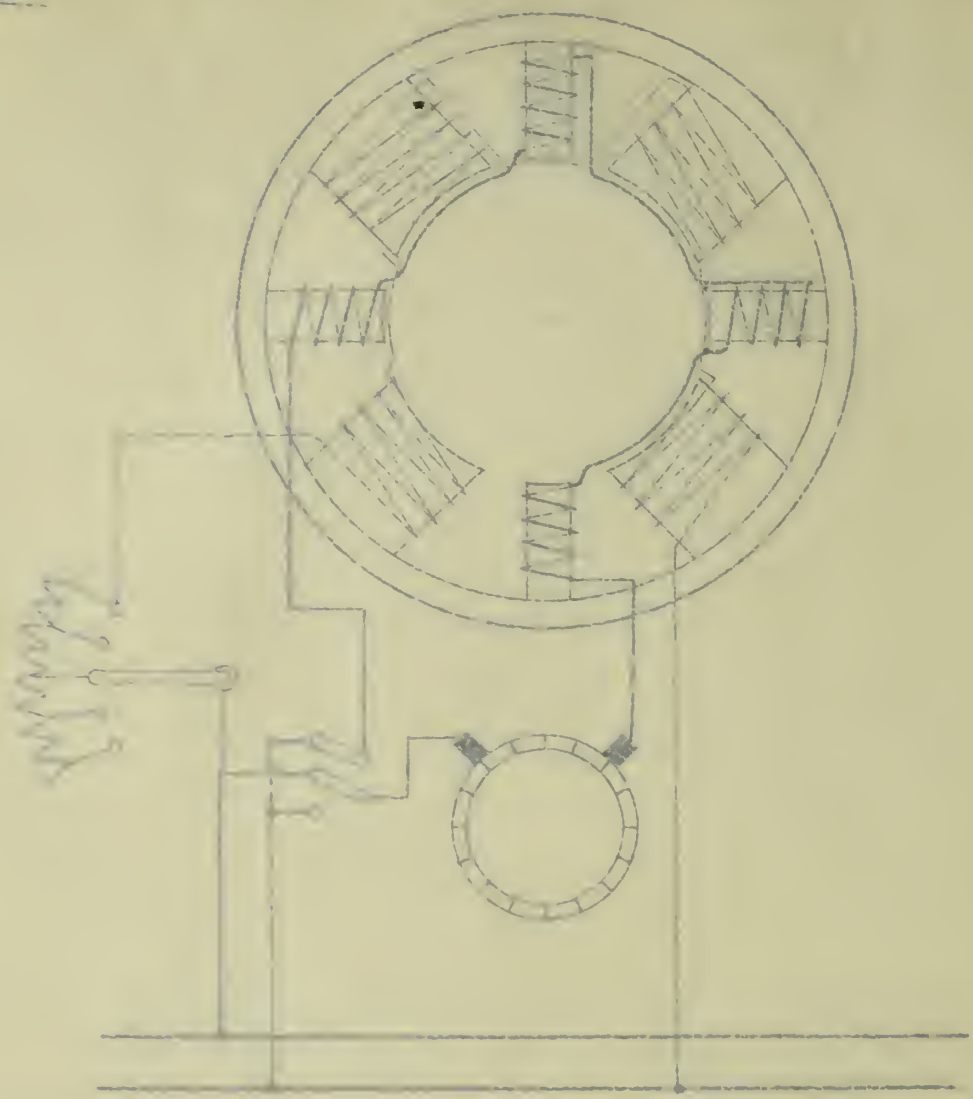


degrees . The difference between consecutive ordinate values gives the increase in pressure for a given angular advance of the pilot brush. This difference is greatest where the slope of the c.m.f. curve is greatest, that is along portion ab of the curve. Since the c.m.f. is proportional to the flux cut, the flux will be a maximum where the change of c.m.f. is greatest. In plotting curves the values for maximum change was taken as 100 percent and othe values in percent of 100.

The accuracy of this method is somewhat impaired because of the variable position of the pilot brush with reference to the moving commutator bars. The pressure indicated being an average for any given position of the brush. The integrated pressure curves eliminate this error to a great extent so that it does not become a very great source of error. The voltmeter readings as taken, are due to the conductors cutting fields of opposite polarity and the flux distribution as determined is really a mean distribution for the two fields.



FIGURE 1.WIRING DIAGRAM SHOWING CONNECTIONS FOR INTERPOLE MOTOR.DIAGRAM OF FIELD FLUX UNDER LOAD IN INTERPOLE MOTOR.

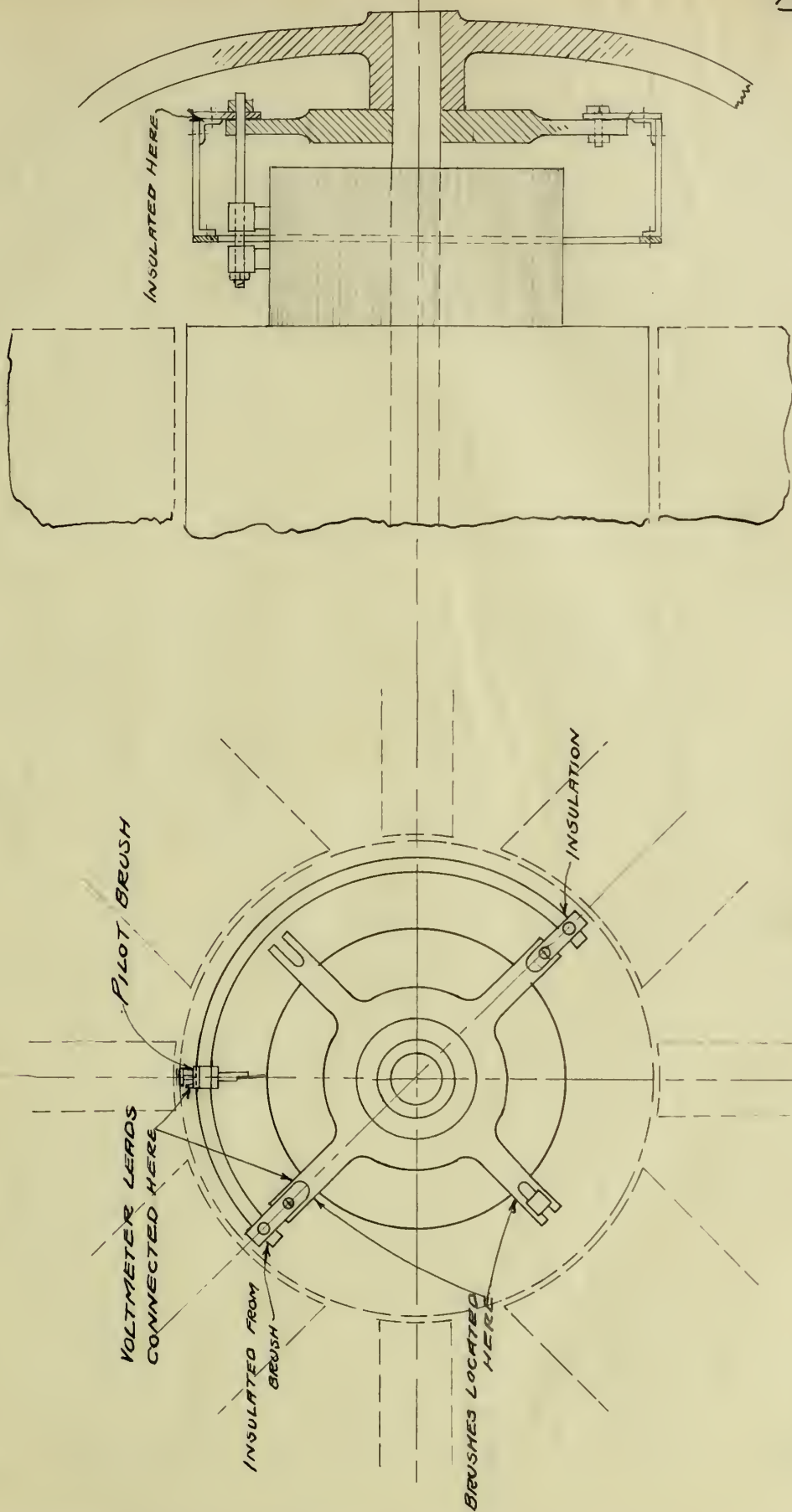


WIRING DIAGRAM SHOWING CONNECTIONS FOR INTERPOLAR COILS



DIAGRAM OF FIELD COIL INTERPOLAR COILS IN REVERSE POSITION

FIGURE 2.



VIEWS SHOWING APPARATUS USED IN OBTAINING VALUES OF E.M.F.  
AT POINTS AROUND COMMUTATOR.



## IV. RESULTS.

In this investigation, due to the method of obtaining the flux waves, only a relative comparison of the theoretical and actual results can be made. The method used permits only of a relative or apparent flux distribution, since no actual values were determined. The derivation of flux distribution from integrated pressure curves is very unsatisfactory inasmuch as the distribution curves must be drawn thru a mean of the points as calculated. This means the results are relative rather than actual.

In comparing the results of this investigation with theoretical results and also with the actual results obtained by B. G. Lamme, it may be said that all agree in the essential details. Minor details due to differences in machines and methods of obtaining the results will account for some of the differences which may occur.

In Plate III. is shown the distribution of various fluxes in an interpole motor as determined by B. G. Lamme. Inasmuch as this investigation deals chiefly with the total or resultant flux, only this part will be used as the basis of comparison. It will be seen from Plate III that the total flux is of such a value at the point of commutation as to assist the reversal of current in the coil under commutation.

Plates IV to VII were obtained from actual data taken in this investigation. Plate IV shows the apparent flux distribution of the machine without interpoles. At half load the flux at the point of commutation is of such a value as to oppose commutation,



and cause sparking. In fact excessive sparking did occur. The apparent high value of flux at the point of commutation was due to the fact that the interpoles were not removed during this test, being merely disconnected. The iron in the path of the armature flux would decrease the reluctance of the path. This would cause an increased magneto-motive force in this region and increase the apparent flux distribution and also distort the shape of the curve as shown.

Plate V shows the apparent distribution of the same machine under full load with interpoles. Here the flux is of such a value and direction as to permit good commutation. The interpoles have enough overcompensating turns to overpower the armature flux and set up a flux in a direction which favors commutation.

Plate VI is merely a comparison between the flux distribution of the motor with interpoles and without interpoles operating at the same load. The difference between the curves at the point of commutation gives an idea of what the interpole does in reversing the flux.

Plate VII shows the effect of speed on the flux distribution. From the curve we see that an increase of speed assists the interpoles. This is really assisting commutation by increasing the load and may be explained as follows. At a given speed the stray power losses are constant. If we increase the speed we must increase these losses proportionally. This means the armature will carry more current. Now if we increase the armature current we increase the armature flux also the interpole flux. Due to the overcompensating turns of the interpole, <sup>h</sup>is would assist commutation, as has already been explained.



It was found that by short-circuiting the interpoles, an appreciable decrease in speed occurred. As the short-circuiting of poles apparently decreases the flux, the reverse of this action might be expected. An explanation of this action is as follows. To decrease the speed of an ordinary direct current motor we may do either or both of two things; increase the field excitation or shift the brushes away from the shift of flux. In short-circuiting the interpoles we do the latter. In decreasing the interpole flux we approach the conditions shown in Plate II, by permitting the armature flux to act again. This is the equivalent of shifting the brushes backward.



## V. CONCLUSIONS.

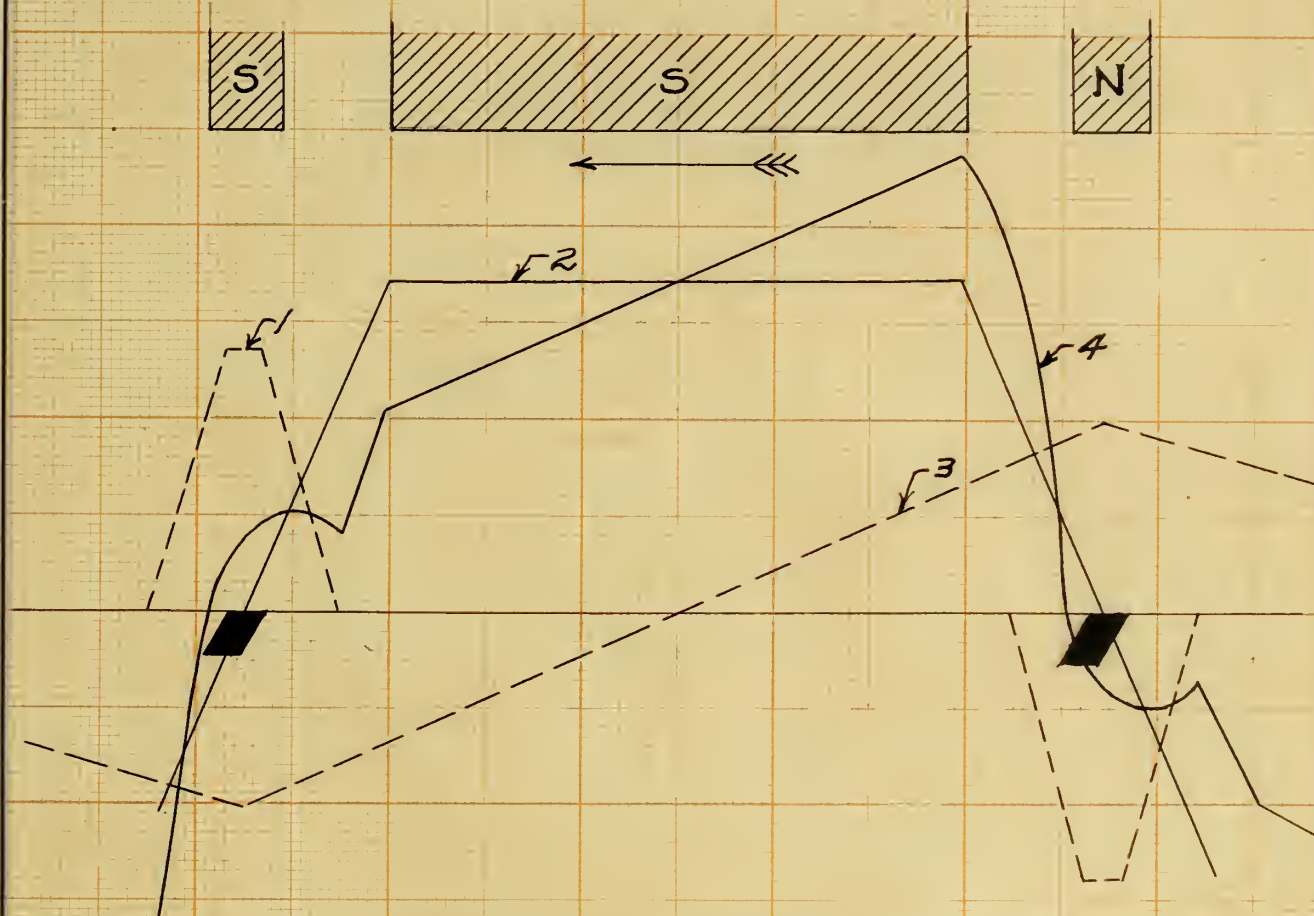
This investigation deals with the flux distribution in interpole motors in a general way only. Nothing original was attempted and most of the theory was obtained from previous investigations of the same nature. The results as determined agree with those of previous investigators, and therefore the same conclusions may be made.

The theory of this investigation applies in a general way to all interpole motors. In some cases the theory would necessarily be modified to meet the case but in general the theory will hold.

The following are some of the conclusions which present themselves from this investigation.

1. The interpole successfully accomplishes its function and prevents sparking due to reactance voltage.
2. The device of the interpole is a decided improvement over shifting the brushes, inasmuch as it offers satisfactory conditions at all loads.
3. The position of the brushes relative to the interpole is important for the successful operation of the latter.
4. Shunting the interpoles is equivalent to shifting the brushes and reduces the speed.

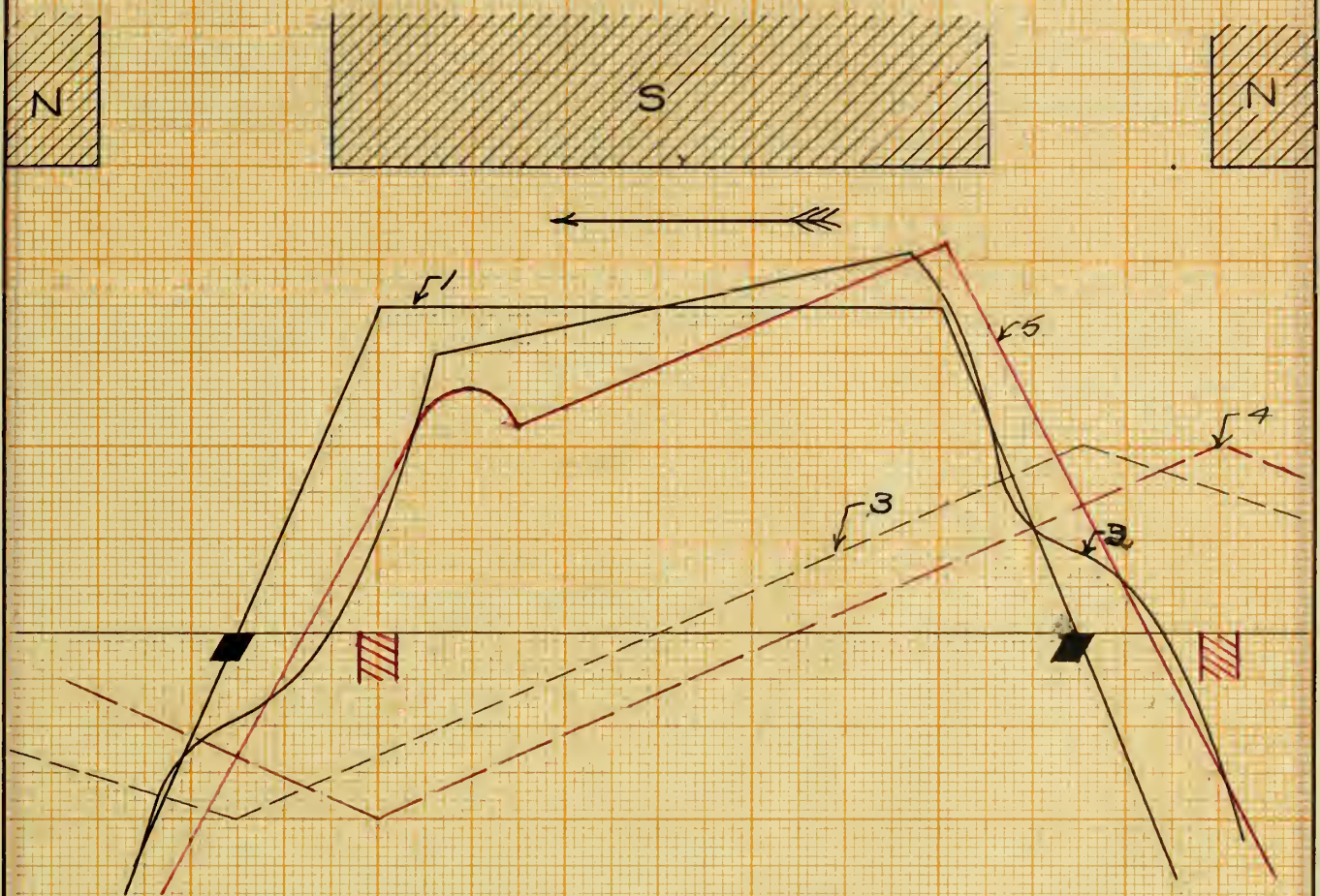




THEORETICAL FLUX DISTRIBUTION  
WITH INTERPOLES.

- 1- INTERPOLE FLUX.
- 2- FIELD FLUX
- 3- ARMATURE FLUX.
- 4- LOAD FLUX. SUMMATION OF 1, 2 & 3.

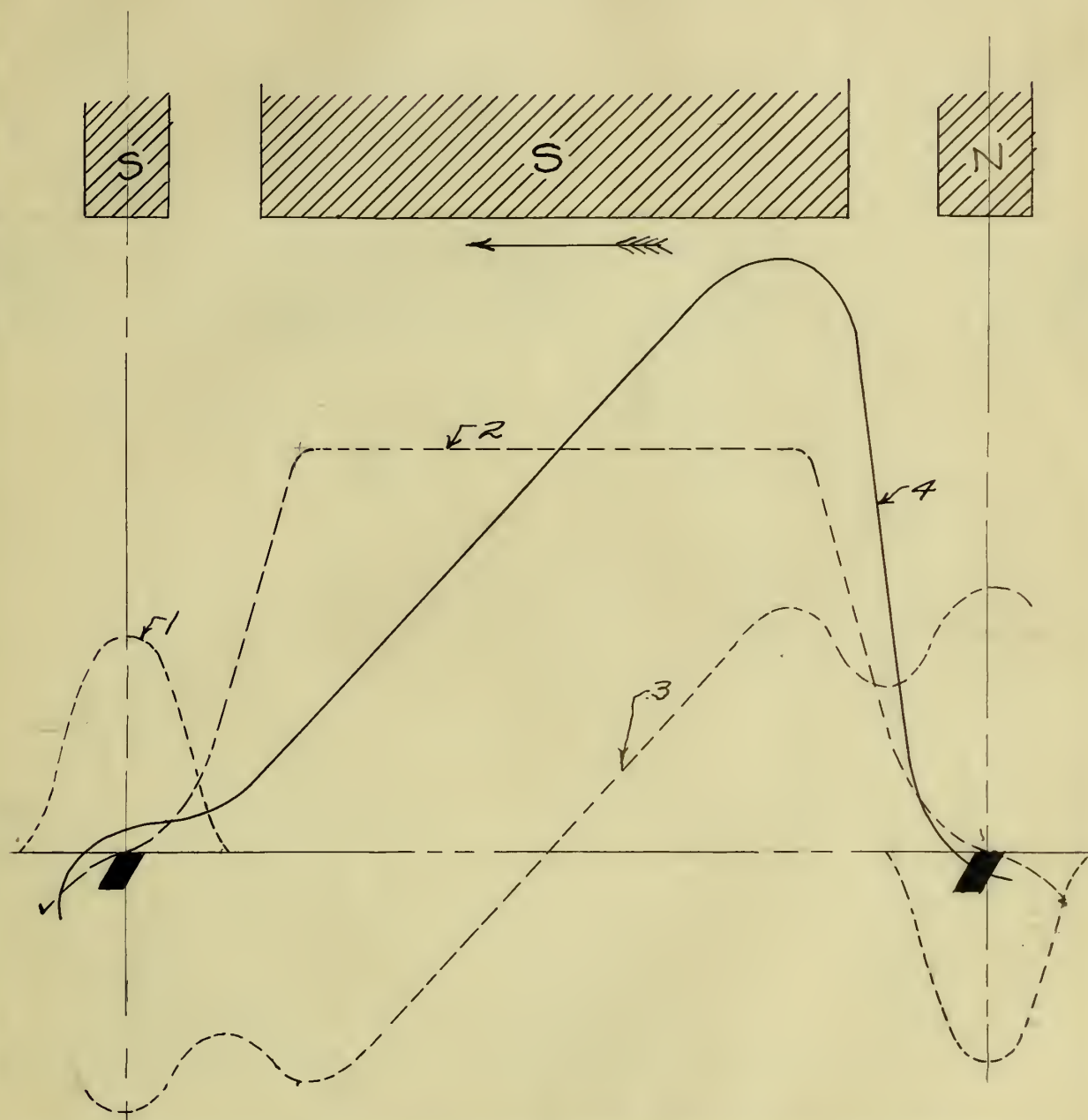
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THEORETICAL FLUX DISTRIBUTION AT LOAD  
AND NO LOAD, WITHOUT INTERPOLES

- 1- FIELD OR NO LOAD FLUX.
- 2- FLUX AT FULL LOAD.
- 3- FLUX DUE TO ARMATURE CURRENT.
- 4- FLUX DUE TO ARM. CURRENT. } BRUSHES SHIFTED
- 5- FLUX AT FULL LOAD } BACKWARD 30°



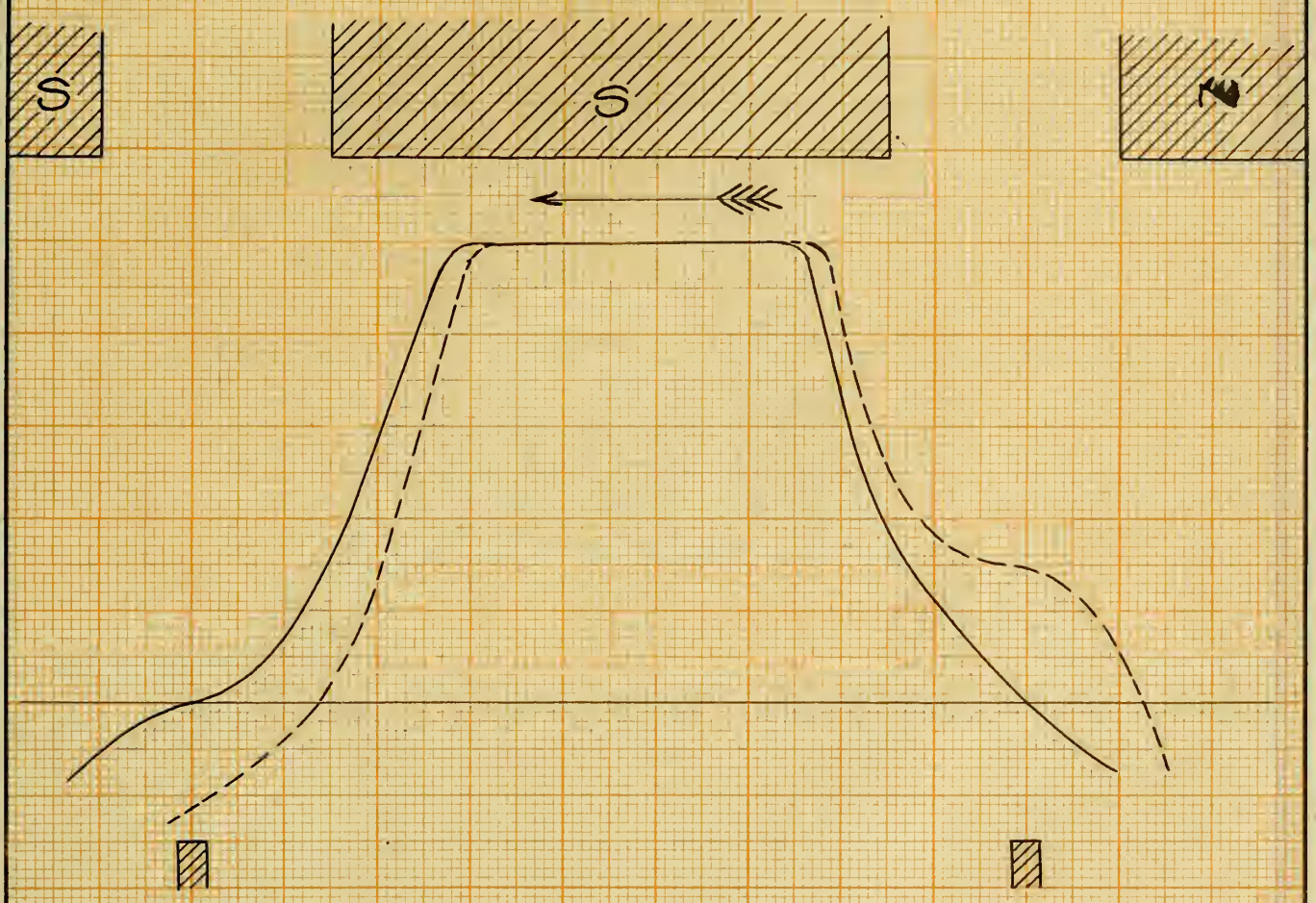


ACTUAL FLUX DISTRIBUTION IN AN INTERPOLE MOTOR.

- 1 - INTERPOLE FLUX.
- 2 - FIELD POLE FLUX.
- 3 - ARMATURE FLUX.
- 4 - SUMMATION OF 1, 2 AND 3.

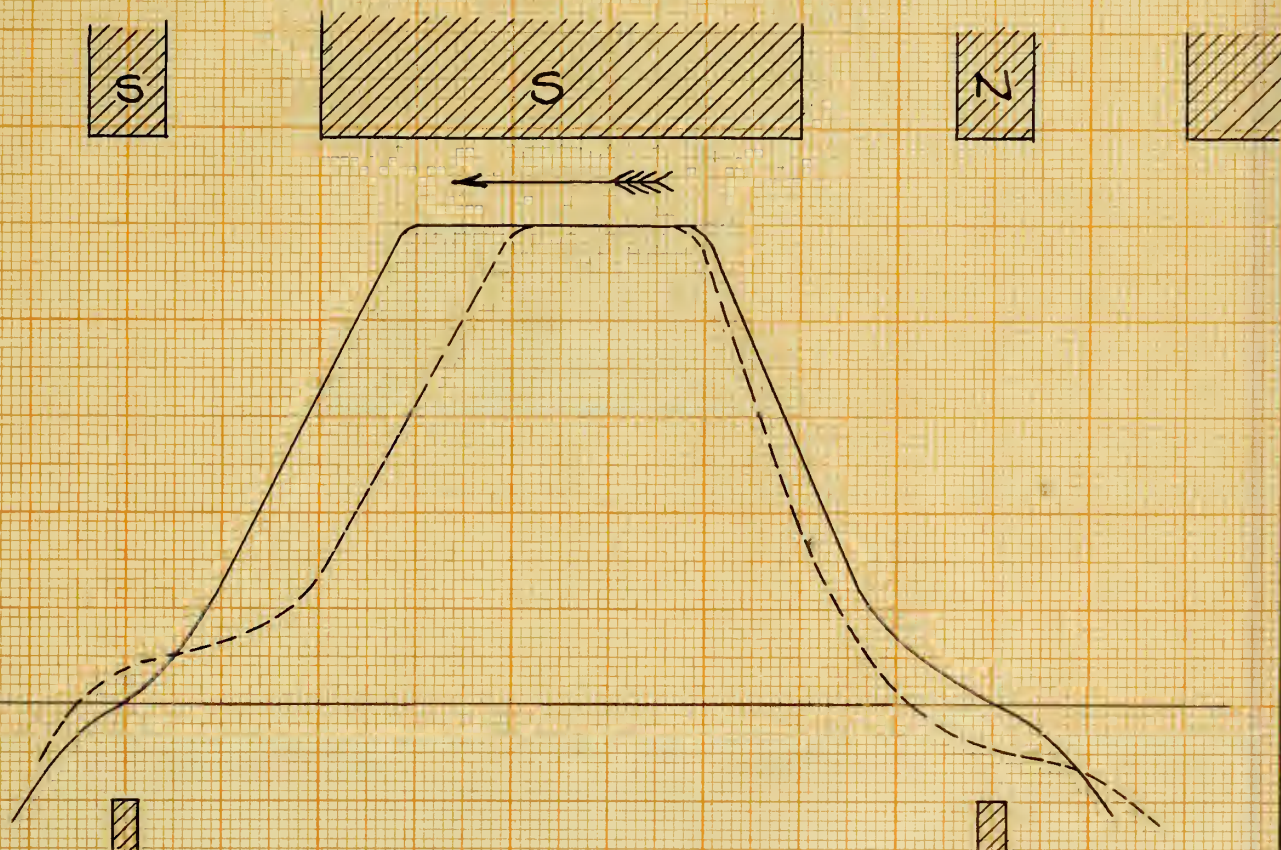


PLATE IV.



BRUSHES ON NEUTRAL  
FLUX DISTRIBUTION WITHOUT  
INTERPOLES.  
— NO LOAD  
--- HALF LOAD

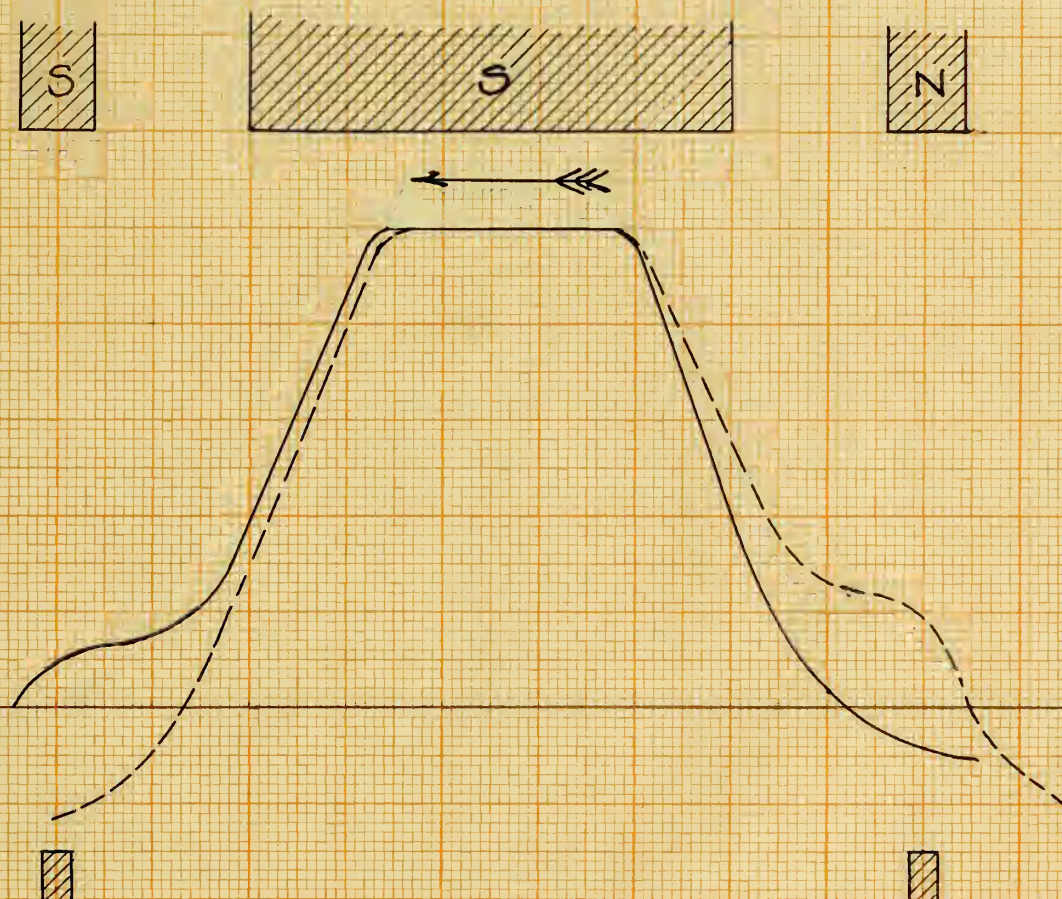




FLUX DISTRIBUTION WITH  
INTERPOLES

— NO LOAD  
--- FULL LOAD.





FLUX DISTRIBUTION WITH INTERPOLES  
AND WITHOUT INTERPOLES.

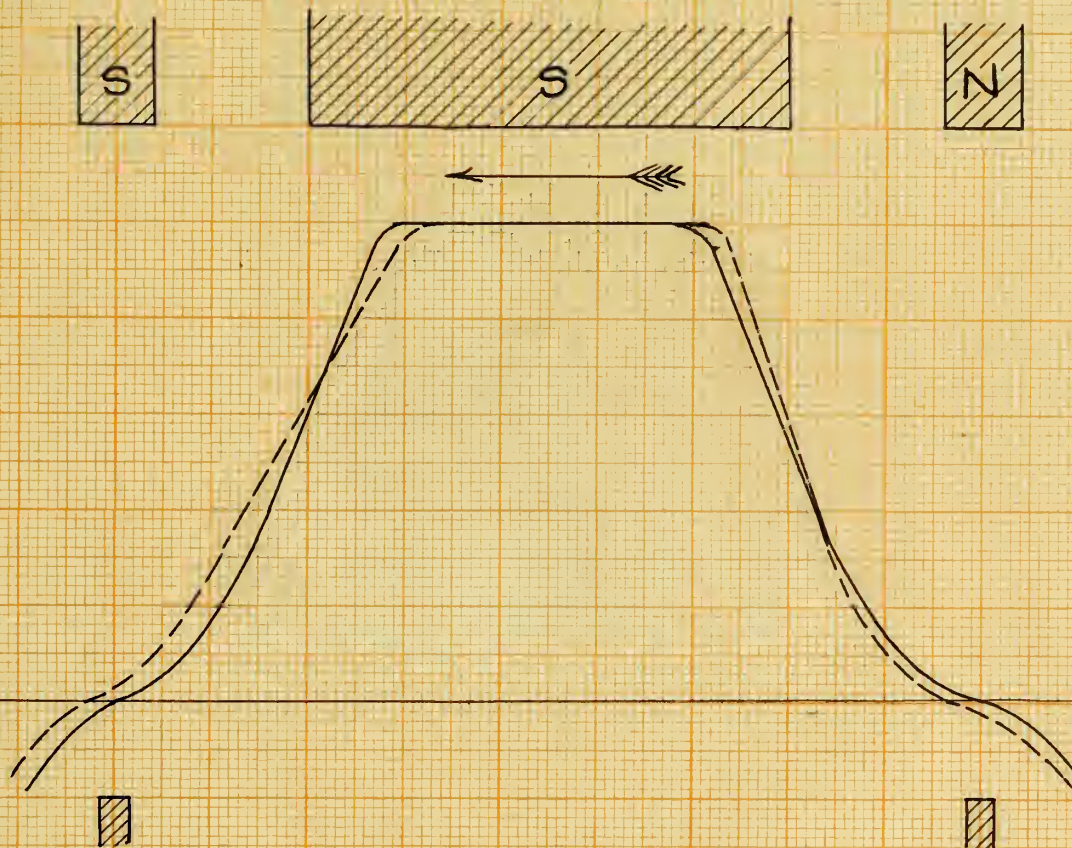
LOAD - 20 AMPS.

SPEED 1500 R.P.M.

— WITH INTERPOLES.

- - - WITHOUT INTERPOLES.





THE EFFECT OF SPEED ON  
FLUX DISTRIBUTION WITH  
INTERPOLES.

LOAD - 8 AMPS.

--- 1050 R.P.M.

— 1950 R.P.M.



## VI. DATA.

Data from test with interpolates.

Degrees	Speed 1200				Speed 1700	
	Load (amps.) 20	30	42	50	50	75
	Volts	Volts	Volts	Volts	Volts	Volts
0	6.5	8.0	9.0	11.0	9.5	12.5
10	2.0	3.0	3.0	4.0	3.0	4.5
20	0.5	1.0	1.0	1.5	1.0	2.0
30	0.5	1.0	1.0	1.0	1.0	1.5
40	1.5	1.5	1.5	1.5	1.5	1.5
50	3.5	3.0	3.0	3.0	2.5	2.0
60	8.5	8.5	7.5	7.5	5.5	2.0
70	20.0	19.0	17.0	17.0	13.0	4.5
80	34.0	31.0	28.0	28.0	21.0	8.5
90	52.5	51.0	45.5	45.0	25.0	17.5
100	71.5	68.5	62.0	61.0	49.0	27.5
110	90.0	85.0	79.5	79.0	63.0	41.0
120	106.0	101.0	96.0	93.0	74.0	55.0
130	127.0	121.0	116.5	114.0	91.0	70.0
140	148.0	140.0	136.0	157.0	108.0	92.0
150	164.0	162.0	160.0	177.0	127.0	124.0
160	181.0	180.0	177.0	196.0	158.0	153.0
170	197.0	197.0	194.0	207.0	176.0	169.0
180	206.0	207.0	205.0	212.0	193.0	180.0
190	211.0	214.0	210.0	213.0	189.0	185.0
200	212.0	213.0	212.0	213.0	191.0	184.0
210	210.0	212.0	211.0	212.0	193.0	183.0
220	208.0	212.0	211.0	212.0	190.0	180.0
230	204.0	208.0	210.0	210.0	188.0	178.0
240	194.0	200.0	207.0	210.0	185.0	
250			200.0	202.5	180.0	



## Data with interpoles.

	No Load 8 amps.			Load 20 amps.		
Speed	1700	1900	1050	1500	1300	1900
Degrees	Volts	Volts	Volts	Volts	Volts	Volts
0	6.0	6.5	7.0	6.5	1.5	1.5
10	1.5	2.0	2.0	2.0	1.0	0.5
20	0.5	0.5	1.0	1.0	1.0	1.0
30	0.5	1.0	0.5	1.0	1.5	1.5
40	1.5	2.5	1.5	1.5	4.0	4.0
50.	4.0	4.0	4.0	4.0	12.0	11.5
60	10.0	10.0	9.5	10.0	25.0	23.0
70	20.5	22.0	22.5	22.0	42.0	39.5
80	35.0	36.0	37.0	35.5	56.0	53.5
90	57.5	56.0	56.0	56.0	75.0	71.5
100	75.0	75.0	76.5	75.0	92.5	90.0
110	94.0	90.0	92.5	93.0	112.5	106.5
120	112.0	112.0	110.0	109.0	136.0	131.5
130	135.0	134.0	139.0	135.0	161.0	159.0
140	153.0	155.0	157.0	153.0	182.0	184.0
150	178.0	178.0	177.0	177.0	198.0	205.0
160	190.0	196.0	196.0	196.0	210.0	219.0
170	213.0	213.0	213.0	216.0	218.0	224.0
180	220.0	220.0	221.0	223.0	218.0	225.0
190	224.0	224.0	226.0	227.0	218.0	224.0
200	224.0	226.0	228.0	227.0	220.0	224.0
210	223.0	225.0	227.0	228.0	218.0	223.0
220	221.0	225.0	226.0	230.0	210.0	213.0
230	219.5	224.0	220.0	227.0	198.0	202.0
240	215.0	218.0	220.0	223.0		
250	206.0	202.0	208.0	217.0		



## Data without interpoles.

Load,	8	8	20	20	30	30
Speed	1500	1120	1120	1500	1500	1500
Degrees	Volts	Volts	Volts	Volts	Volts	Volts
0	5.0	4.0	8.0	10.0	13.0	14.0
10	3.0	2.0	4.2	6.5	9.5	9.0
20	1.0	1.0	1.5	2.0	3.5	3.0
30	-0.5	0.0	-1.5	-2.0	-3.0	-4.0
40	-0.5	1.0	-2.0	-4.0	-6.5	-6.5
50	4.0	6.0	2.0	0.5	-4.5	-3.5
60	15.0	17.0	12.0	10.0	5.0	6.0
70	33.0	34.0	26.0	24.0	18.0	19.0
80	48.0	50.0	40.0	39.0	30.0	33.0
90	69.0	72.0	60.0	59.0	50.0	53.0
100	87.0	90.0	78.0	80.0	66.0	70.0
110	106.0	106.0	95.0	96.0	82.0	88.0
120	122.0	123.0	112.0	114.0	99.0	105.0
130	143.0	140.0	131.0	136.0	120.0	130.0
140	162.0	162.0	150.0	154.0	139.0	150.0
150	184.0	184.0	172.0	178.0	163.0	174.0
160	202.0	199.0	191.0	198.0	189.0	192.0
170	212.0	210.0	204.0	210.0	201.0	204.0
180	216.0	214.0	208.0	216.0	206.0	210.0
190	218.0	212.0	211.0	219.0	212.0	215.0
200	220.0	214.0	214.0	220.0	217.0	222.0
210	222.0	214.0	218.0	225.0	222.0	228.0
220	223.0	216.0	220.0	227.0	224.0	232.0
230	220.0	212.0	218.0	226.0	216.0	231.0
240	211.0	202.0	210.0	218.0		224.0
250	193.0	188.0	196.0	208.0		208.0





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